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PROGRESS REPORT ON THE INVESTIGATION OF THE PROPERTIES OF ILLINOIS SHALES AND CLAYS AS MORTAR MIX

By

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Cooperative Investigation
of the
Illinois State Geological Survey
and the
Department of Ceramic Engineering of the
University of Illinois

INTRODUCTION

The use of clay materials as an ingredient in cement mortars is not a new idea. Many instances of such a practice have been noted over a long period of years but the possibilities of commercial development of clays as mortar mix materials have been seriously considered only in recent years. Such a development has taken place in some regions and with marked success.

A number of experimental studies have been made on the properties of mortars containing clay materials. These have demonstrated the practicability and desirability of the use of clays and shales of certain regions or localities. In these investigations, the characteristics of the clay materials themselves and the relation of their specific properties to their effects in mortar mixtures have not received adequate consideration. The results, therefore, have applied to the particular clays investigated and have not been entirely conclusive as regards the advantages or disadvantages of clay materials from other regions.

The present investigation was undertaken by the Illinois State Geological Survey in cooperation with the Department of Ceramic Engineering at the request of the Illinois Clay Manufacturers' Association and of members of the Structural Clay Products Institute.

In planning the investigation it was felt that, in certain respects, the study should be more comprehensive than previous work has been. In particular, the physical and mineralogical characteristics of the materials should be determined in order to inquire into the effects which these might have on the properties of mortars and to disclose whether or not certain types of clay or shale might be more desirable than others.

Samples of various clays and shales of the State were collected by the staff of the Geological Survey. Physical tests to determine the particle-size characteristics of these materials were made by Dr. R. M. Grogan under the direction of Mr. J. E. Lamar, Head of the Industrial Minerals Division, and mineralogical examinations were made by Dr. R. A. Rowland under the supervision of Dr. R. E. Grim, Petrographer. The investigation of the properties of mortar mixtures in which these clay materials were incorporated has been conducted in the laboratories of the Department of Ceramic Engineering by Mr. P. E. Buckles under the direction of Professor R. K. Hursh.

Samples and Sampling

The samples for this investigation were selected on the premise that the materials studied should include: (1) Samples representative of the various kinds of shales, underclays, and surface clays now in use in Illinois for the manufacture of clay products;

(2) samples of Illinois shales, clays, or other materials not used fo making clay products but which are of interest because of their mineral or mechanical composition; (3) samples giving a resonably complete representation of the kinds of clay minerals found in Illinois clays and shales as well as the amounts of clay minerals and the various combinations in which they occur; and (4) samples giving a reasonably complete representation of the various ranges in particle size distribution existing in the clays and shales of Illinois.

By selecting samples on the above basis, it was believed that practically all types of clays and shales occurring in Illinois would be represented and that the data resulting from the testing of these samples could be interpreted to evaluate the suitability of the bulk of Illinois' clay and shale deposits for mortar mix. Thus it was felt that the clay products industry of the State as a whole would be served adequately without an investigation of overwhelming proportions and prohibitive duration.

From a more purely scientific angle it was also felt that samples chosen as indicated above would provide a sound basis for determining the significance of particle size distribution and clay mineral composition in relation to the various important properties of the mortars in which clay or shale mortar mixes are used.

With the foregoing factors in mind, 22 samples were selected for study. With the exception of the sample of gumbotil, all materials are in actual commercial use for the manufacture of clay products or other purposes. The samples included 10 samples of shale from sources well distributed throughout the State and covering a wide range in the amount of clay minerals content present and in particle size distribution or texture; three samples of underclays, or fireclays as they are sometimes known, of varied clay mineral composition and texture; three samples of till, a pebbly, mostly limy, clay of glacial origin; one sample of gumbotil, a non-limy clay occur ring extensively in southern and western Illinois and resulting from the weathering of glacial till under conditions of poor drainage for a long period of time; one sample of Illinois fuller's earth, used for decolorizing oil and for other purposes; one sample of southern Illinois kaolin, a material with a high percentage of the clay mineral kaolinite; one sample of "Coal Measures" clay with an unusual mineral composition; one sample of loess, a wind-transported and deposited material found extensively along the major rivers of western and southern Illinois; one sample of crude silica, a material consisting almost exclusively of various sized aggregates of exceedingly minute quartz particles. The last sample was included to permi evaluation of the possible significance of non-clay materials as mortar mix.

With a few exceptions, samples consisted of 200 pounds of dried brick taken at random from dryer cars. It was felt that such samples would be reasonably representative of the raw materials in us and would be similar to the dryer waste which in some places is an important source of clay from which mortar mix is made.

A few shale samples contained small amounts of barium carbonate that had been added to reduce scumming. Such samples were duplicated by additional 200-pound samples of barium-free shale from storage bins so that both barium-containing and barium-free material would be available for study. For the most part the samples were supplied directly by various clay manufacturers and producers.

PARTICLE SIZE CHARACTERISTICS OF SAMPLES

By J. E. Lamar

It is well known that the properties of clays and shales vary with the particle size of their constituent mineral grains. It seemed desirable, therefore, to make particle size measurements of the samples used in this investigation with the particular aim of determining the effect of particle size on the quality of a clay or shale for mortar mix and whether particle size will serve as a means of distinguishing between suitable and unsuitable clays and shales.

The particle size of a clay or shale is difficult, if not impossible, to measure in absolute terms. The violence of the dispersion method used, and the length of time during which a sample is subjected to a dispersing procedure will influence the extent to which a shale or clay is broken down towards its ultimate particle size. The present study makes no claims to have reached ultimate particle size but the dispersion processes employed are believed to give results satisfactory for all practical purposes and to be at least as severe as any conditions producing dispersion likely to be encountered in actual use of clays or shales as mortar mix.

Method of Analysis

Particle size analyses were made by the "hydrometer" method using a Casagrande type hydrometer. This procedure has been investigated and described by a number of different writers and has been found accurate and comparatively rapid. Briefly, it consists of measuring by means of a hydrometer the amount of a sample of known weight which remains in suspension in water after certain stated periods of time and from these data drawing a curve showing particle size distribution.

Each sample analyzed consisted of a representative fraction of the original 200-pound sample which had been ground to pass an 8-mesh sieve. Preparation of samples for analysis involved the use of sodium oxalate to give maximum dispersion and five cycles of soaking and shaking in an end-over-end shaker, each cycle consisting of four hours shaking and 20 hours soaking, making a total of 20 hours of shaking and 100 hours of soaking for each sample. At an appropriate place in the dispersion procedure the samples were rubbed lightly on a 270-mesh sieve to break up unslaked pieces.

After the hydrometer analyses were completed, the plus 270-mesh material was recovered by wet screening and was dried and weighed. The character of this coarse portion of the samples was identified under the microscope and proved to be largely grains of quartz, siltstone, clay ironstone, and brown ferruginous material.

All samples were run in duplicate and close checks were obtained in all cases. The data given are the averages of the results of the duplicate analyses.

Results of Tests

Results of the particle size analyses are shown graphically in figures 1 and 2. Each group of bars represents one sample and the length of each bar shows the amount of material of a certain size. The key in figure 1 gives the size of the material represented by each bar.

These bar charts show that the samples studied have a diversity of particle size distributions. Of the shales, samples 5, 20, and 21 (figure 1) contain a large amount of fine material and very little coarse material, in contrast with shales 4, 8, and 18 which have a relatively small amount of fine material and a large amount of medium and coarse material. Other shale samples show intermediate characteristics.

The charts of the fireclays, tills, etc. (figure 2), show a similar diversity of particle sizes. The kaolin, fuller's earth, and "Coal Measures" clay have very large amounts of fine materials whereas other samples contain moderate amounts or comparatively small amounts.

It is probable that the particle size character of clays and shales bears a relationship to their suitability for mortar mix. Evaluation of this relationship involves the consideration of many complex factors and is not feasible at the present stage of this investigation.

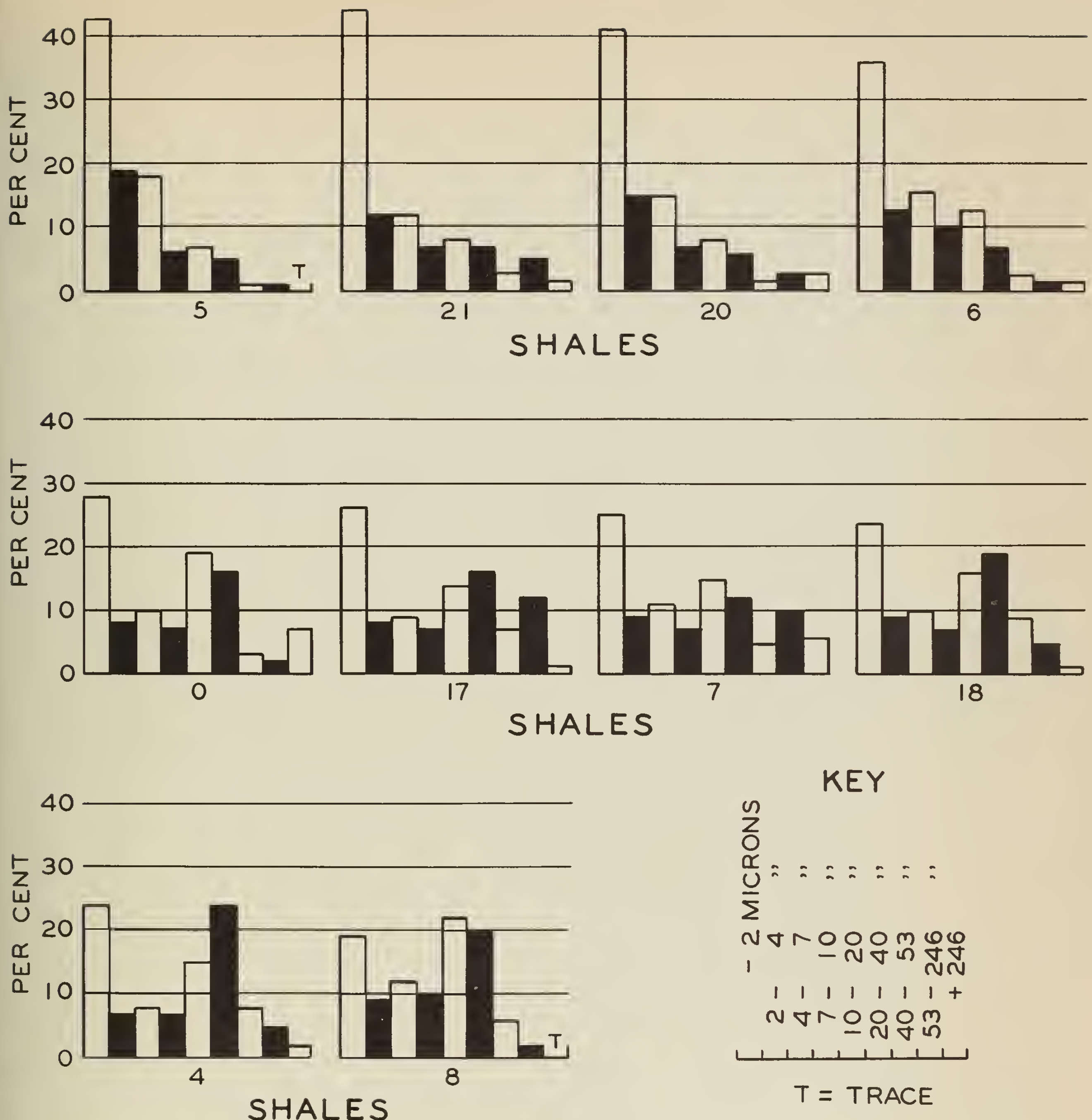

Fig. 1. - Chart showing the particle size character of the shale samples.

Lengths of the vertical bars indicate the amount of material present within the size ranges given in the "Key." The numbers below each graph indicate sample numbers.

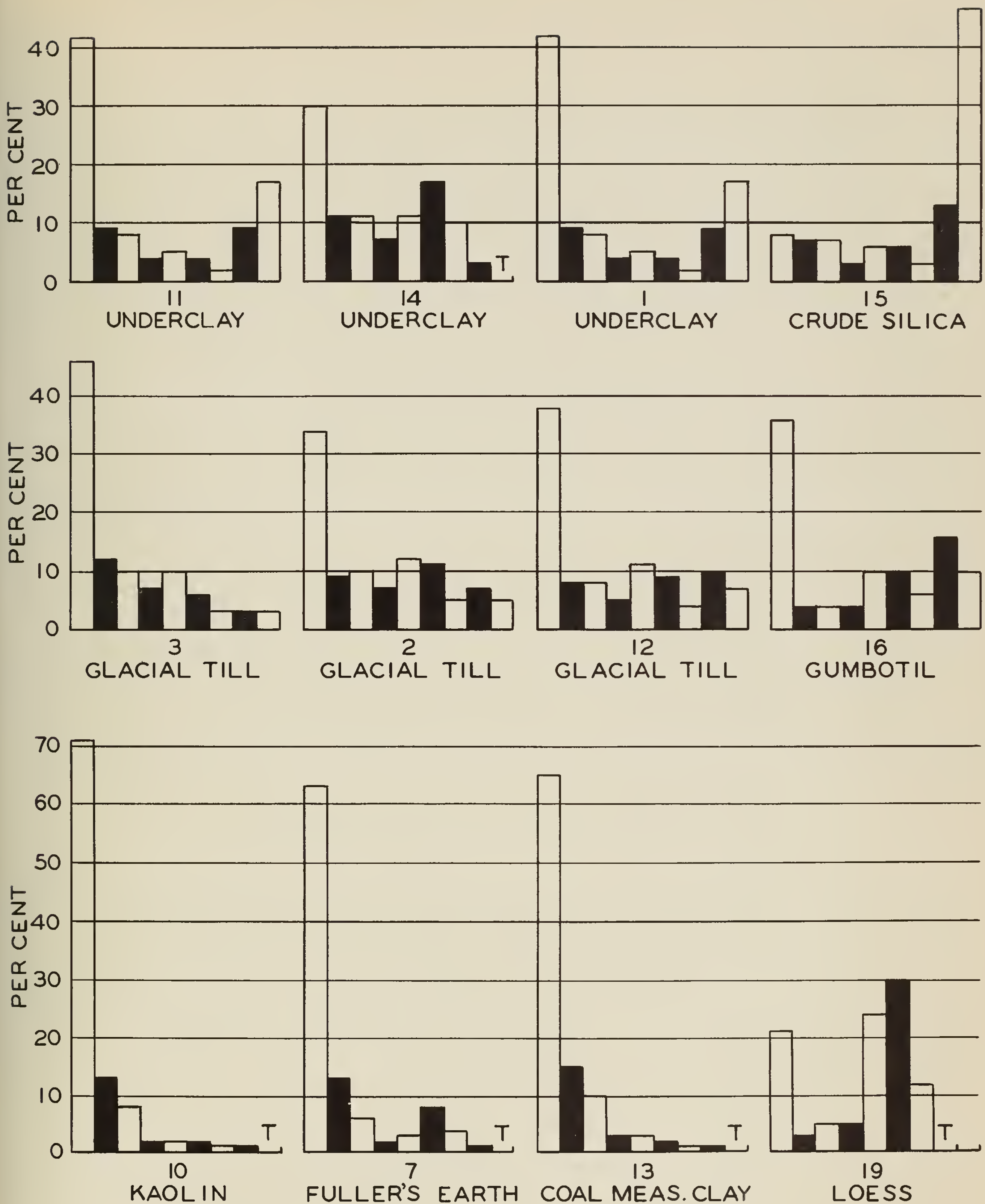

Fig. 2. - Chart showing the particle size character of the underclays, tills, and other samples studied. The "Key" is given in figure 1.

MINERALOGICAL CHARACTER OF THE CLAYS AND SHALES

By Ralph E. Grim

Clays and shales are aggregates of very small crystalline particles of one or more members of a small number of minerals known as the clay minerals. Analyses of many clays and shales have shown that there are three important groups of clay minerals and these are listed in table 1. In addition to the clay minerals, clays and shales also contain variable quantities of quartz, pyrite, organic material, limonite, etc. Of these non-clay mineral constituents, quartz is usually the most abundant, so that in a general way clays and shales are composed of clay mineral flakes of the order of size of 0.001 mm. or 1/25000 in., together with variable quantities of grains of quartz.

Table 1.--Important Clay Minerals

Name	Ideal Composition	Occurrence
Kaolinite	$(OH)_8Al_4Si_4O_{10}$	China clay, underclays, etc.
Illite	$(OH)_4Ky(Al_4 \cdot Fe_4 \cdot Mg_4 \cdot Mg_6)(Si_{8-y} \cdot Al_y)O_{20}$	Shales, underclays, surface clays
Montmorillonite	$(OH)_4Al_4Si_8O_{20}$	Bentonite, fuller's earth, surface clays

Composition of Clay Materials

Following are brief statements of the general composition of certain types of clay materials. Most of the shales that have been studied are composed essentially of flakes of illite ranging in size from about 0.001 mm. to 0.020 mm. Some shales contain almost no quartz whereas others contain 50 per cent or more in grains from about 0.002 mm. to 0.2 mm. China clays are composed largely of flakes of kaolinite, ball clays of kaolinite with some illite, fireclays of kaolinite with some illite. Like the shales the fireclays also contain quartz in amounts varying up to more than 50 per cent. Also in the fireclays the relative amounts of illite and kaolinite vary; thus some fireclays are known that are composed almost entirely of kaolinite whereas others contain about equal amounts of kaolinite and illite. The clay mineral in most fuller's earth and bentonites is montmorillonite. Surface clays in Illinois frequently contain illite as the essential clay mineral constituent; grains of quartz and also of calcite, if the clay is calcareous, are usually abundant. Gumbotil, the clayey material produced by the ancient weathering of till, contains illite and montmorillonite, and occasionally small amounts of kaolinite.

Properties of the Clay Minerals

The clay minerals have different physical properties, and the physical properties of any clay or shale depend largely on the character of the clay minerals that compose it. The amount and kind of non-clay minerals are also important; for example, a clay containing 50 per cent quartz will not have the same properties as one containing only 10 per cent quartz. Some of these properties are no doubt related to the satisfactory use of a clay for mortar mix, and i is one of the objectives of this work to investigate this point.

Montmorillonite is found in extremely small particles (frequently less than 0.0001 mm.) or in larger flakes that are easily broken down, namely, in pugging, to this extremely small size. Clays composed of montmorillonite have high plastic properties, high bonding strength, high shrinkage, and are not refractory.

Kaolinite occurs in particles larger than those of montmorillonite (usually larger than 0.001 mm.) and the particles are not easily reduced in size on working as in pugging. Kaolinite clays tend to have lower shrinkage, bonding strength, and plastic properties than montmorillonite clays. They are also more refractory.

Illite may occur (1) in particles of very small size or in particles that are easily broken down to an extremely fine particle size, or (2) in larger flakes that resist reduction in size. Clays composed of the former variety are plastic and have high shrinkage and high bonding strength. Materials composed of the latter variety have low shrinkage, low bonding strength, and low plastic properties. In general, illite clays or shales are not refractory.

Analytical Results

It is possible to classify clay materials on the basis of their clay mineral composition and also on the basis of the relative abundance of quartz. The Illinois Geological Survey has determined the composition of all the important kinds of clays and shales in the State. Using these analytical data as a basis the samples included in the present investigations were selected so that they would represent the range in composition of clays and shales found in Illinois. The purpose of this selection was twofold: first, to place the investigation on a fundamental rather than empirical basis by providing for the study of the basic factors that determine the satisfactory use of a material for mortar mix; second, to permit a prediction to be made of the probable worth of any clay or shale in the State for mortar mix. This follows from the fact that if we know what composition a material must have to be used satisfactorily for mortar mix, we can predict the probable value of a clay or shale for this use by determining its composition.

Table 2 presents data on the character and abundance of the clay minerals and the amount of quartz in the samples investigated. The shales range in composition from about 85 to 45 per cent illite, the remainder being chiefly quartz. The illite in the shales is the variety that occurs in relatively large particles which do not break down easily into extremely small ones. The underclays show a range in clay mineral content of from 60 to 70 per cent and a variation in the relative abundance of illite from 10 per cent to 30 per cent of the total clay. The clay mineral in the glacial till is illite, probably of the variety occurring in large flakes which are resistant to break-down. The non-clay portion of the glacial tills contains in addition to quartz, grains of calcite making up about 15 per cent of the total sample.

The kaolin sample is almost pure kaolinite and is distinctive because the kaolinite occurs in flakes smaller than those frequently characteristic of this mineral. Sample 13 contains only about 10 per cent non-clay mineral and the illite is of the variety that breaks down easily into extremely small particles when worked with water. The fuller's earth is illustrative of clays composed chiefly of montmorillonite. Samples 16, 19, and 15 are examples of fine-grained materials with large amounts of non-clay minerals. Gumbotil (sample 16) is also important because of the presence of a small amount of montmorillonite. It is known that this clay mineral, even though present in only small amounts, has a very great effect on the physical properties of a clay.

The study of the possible relation between the mineral compositions of the clays and shales and the properties that determine their suitability for mortar mix, which is one of the objectives of these researches, cannot be made until all the analytical data are at hand. Consequently, the results of this part of the work cannot be presented prior to the final report.

Table 2.--Mineral Composition of Samples Investigated

Sample no.	Clay minerals	Clay minerals per cent	Size of clay minerals*	Chief non-clay minerals	Maximum size of non-clay mineral	Comments
0	illite	60	medium	quartz	.05 mm.	Contains grog and limonite
1	illite (10) kaolinite (90)	70	fine	quartz	.2 mm.	Contains grog
2	illite	45	fine	quartz 70 calcite 30	2 mm.	
3	illite	60	fine	quartz 60 calcite 40	.5 mm.	Contains limonite

(Continued on page 8)

Table 2.--(Continued)

Sample no.	Clay minerals	Clay minerals per cent	Size of clay minerals*	Chief non-clay minerals	Maximum size of non-clay mineral	Comments
4	illite	45	coarse	quartz	.2 mm.	Contains limonite
5	illite	85	fine	quartz	1 mm.	Contains limonite
6	illite	85	medium	quartz	.15 mm.	Contains abundant li-onite (5±%
7	illite	60	coarse	quartz	.15 mm.	Contains limonite
8	illite	70	coarse	quartz	.5 mm.	
9	montmorillonite	75	fine	quartz	.2 mm.	Contains glauconite, feldspar, & coarse mica
10	kaolinite	95	fine	quartz	.06 mm.	
11	kaolinite (50) illite (50)	60	medium	quartz	.3 mm.	
12	illite	40	fine	quartz 65 calcite 35	.2 mm.	Contains limonite
13	illite (80) kaolinite (20)	90	medium	quartz	.06 mm.	Contains appreciable pyrite
14	illite (35) kaolinite (65)	60	medium	quartz	.15 mm.	Contains appreciable pyrite
15	kaolinite	5	fine			Non-clay material is crypto-crystalline silica in aggregate form
16	illite montmorillonite	40	fine	quartz	1 mm.	
17	illite	50	coarse	quartz	.25 mm.	

(Continued on page 9)

Table 2.--(Continued)

Sample no.	Clay minerals	Clay minerals per cent	Size of clay minerals*	Chief non-clay minerals	Maximum size of non-clay mineral	Comments
18	illite	60	medium	quartz	.2 mm.	Contains trace of calcite & few larger pebbles
19	illite	20	fine	quartz	.15 mm.	
20	illite	75	medium	quartz	.3 mm.	Contains limonite
21	illite	75	coarse	quartz	.3 mm.	Contains limonite

* Coarse = +0.02 mm.; medium = 0.02 mm.-0.005 mm.; fine = -0.005 mm.

PROPERTIES OF MORTAR MIXTURES CONTAINING ILLINOIS CLAYS AND SHALES

By R. K. Hursh

The proportion of clay which may be satisfactorily incor-
porated in the mortar is a most important consideration. Whether or not certain types of clay material could be used in larger amounts than others and the practicable limit for each material were questions to which these experiments were directed. For each sample a series of mixtures was prepared in which the clay and cement proportions were varied while a standard proportion of sand was maintained. These mixtures covered a range which, it was felt, extends beyond the practicable maximum clay content for actual use. Comparison of the clay-cement-sand mortars with lime-cement-sand mortars and with commercially prepared masonry cement mortars has also been made.

It has been the practice, in other investigations and in general commercial use of clays in mortars, to grind the material very finely. It seemed desirable to determine what effect on the mortars would result if the clay or shale were not so finely ground. The cost of fine-grinding is an important factor in the practicability of commercial development of these materials for mortar mix in many of the plants which do not, at present, have equipment for such preparation of the material. Successful use of clays of relatively coarse grind in mortars has been reported. A series of tests have, therefore, been made of mortars in which the clay portion was ground only in the dry-pan to pass an 8-mesh screen. For comparison, tests have also been made on mortars in which the same clays and in like proportions have been used but with relatively fine-ground clay material passing the 80-mesh sieve. A few additional tests were also made with clay material ground even more finely.

Test Procedure

So far as possible, standard methods of test procedure, approved by the American Society for Testing Materials, have been used in the investigation. Such standards are not available for testing some properties or characteristics, such as plasticity, and in these cases, suitable test procedures must be developed to give comparative data.

Materials and Mixtures.--A single brand of a standard Portland cement was used and a sand from the Ottawa district which conformed to the A.S.T.M. specification of C-41 for mortar sand for compression tests. The sizing specification for such sand and the screen analyses of two lots of sand used in these tests are shown in table 3

Table 3.

Screen size U.S. series equivalent	Percentage retained on designated screen: A.S.T.M. specification C-41	Test samples: 1	Test samples: 2
100	98 ± 2	97.0	97.0
50	72 ± 5	76.0	67.0
30	2 ± 2	0	0.5
16	0	0	0

Mortar mixtures were prepared in the proportions of one (1) part by weight of cementing material (cement plus clay) to three (3) parts by weight of mortar sand. These proportions correspond to the A.S.T.M. Specification C91-38T for compressive tests on mortars. The amount of sand was the same in all the mixtures, 75 per cent of the total.

The proportions of clay and cement were varied so that, for each clay, four mortars were made with ratios of clay to cement of 20:80; 30:70; 40:60; 50:50 respectively, the proportions being by weight. Tests have been made with both coarsely- and finely-ground clays in these proportions.

The water requirement for each mixture to give standard consistency was determined by means of the flow table. For preparation of compression test specimens, a flow of 65-80 per cent is designated. Experimental mixtures were made up with varying water content until the proper amount of water to give the desired flow was found.

Compressive Strength.--Strength of mortars in compression is determined by tests on 2-inch cubes. These are made, by a standardized procedure, in metal molds with mortars of a standard consistency. The cubes are left in the molds for 48 hours in a damp closet with regulated temperature and humidity. They are then removed from the molds and stored for an additional five days in the damp closet. Specimens are then tested, without drying, for the seven-day strength of the mortar. For longer curing periods, the mortar cubes are removed from the damp closet at the end of the seven-day period and are immersed and kept under water for the additional time, after which they are tested, without drying, for compressive strength. In the present investigation, compressive tests were made on six cubes of each mixture after seven days and on another six cubes after 28 days. Individual specimens which showed a variation of more than 10 per cent from the average were discarded. The test pieces showed excellent uniformity and only a few were eliminated.

Water Retention.--The water retentivity of a mortar is considered to be in a measure an index to its workability, which is an essential property of a mortar. It also indicates somewhat the resistance of the mortar to drying out in contact with absorbent masonry units with consequent weakening of the bond.

The water retention test is made by subjecting a layer of the mortar, made up to a consistency giving a flow of 100-115 per cent, to a suction equivalent to a two-inch column of mercury for a period of one (1) minute. After the suction treatment a flow test is made, and the result is recorded in percentage of the original flow. Federal Specification SS-0-181b requires that the final flow be at least 65 per cent of that before the suction test. The water retention tests are not completed at this time and only part of these data are given.

Further tests on the mortars include time-of-set, volume changes in setting and due to subsequent wetting and drying, and some bonding or adhesion tests of typical mortars with brick masonry. Results of these tests will be reported at a later date.

Results

Compressive Strength.--The average compressive strength of mortars in which the various shales were used to replace 20, 30, 40 and 50 per cent of Portland cement in a 1:3 mixture are shown by curves in figure 3. The solid lines marked 7-C and 28-C represent the seven-day and 28-day tests of mortars in which coarsely-ground shale passing an 8-mesh sieve was used. Similar data for the more finely-ground material passing an 80-mesh sieve are shown by the dotted curves 7-F and 28-F. The sample number of each shale accompanies the corresponding curves. For comparison, the strength tests for mortars containing hydrated lime in the same proportions as the shales are shown in the curves under L. The seven- and 28-day strength of a commercial masonry mortar are shown by points 7-M and 28-M respectively on this diagram. The strength data for a 1:3

cement-sand mortar are also shown by points 7-PC and 28-PC at the left-hand margin.

Data for the underclays and glacial tills are presented in the curves of figure 4 and those for other miscellaneous samples in figure 5.

With 20 per cent clay and 80 per cent cement, there is a slight gain in strength at seven days over the use of cement alone in the 1:3 mortar in shale samples 6, 8, and 17; about equal strength with samples 5, 7, and 4; and lower compressive strength with other shales. One of the underclays (14) shows about equal strength with the 20:80 ratio, and all of the glacial tills are only slightly lower in strength than the cement-sand mortar when used in this proportion. Fuller's earth (9), silica (15), loess (19) and two of the underclays (1 and 11) show definitely lower values of strength at seven days, even with the smallest amounts replacing cement in the mortar.

All of the clay materials cause a progressive decrease in mortar strength as the percentage of clay is increased. The change is approximately proportionate to the amount of clay added. The decrease in strength is slightly less pronounced in shales 5, 7, and 0 and in underclays 1 and 11 than in the other materials, as indicated by the slope of the lines in figures 3 and 4.

As would be expected, there is a definite gain in strength in the period from seven to 28 days, during which the test cubes were immersed in water. The amount of gain is smaller for shales 20 and 17 and for the kaolin (10) than for the other materials. The numerical value of the increase in strength is greatest for the smaller clay additions but the gain is in nearly the same ratio to the seven-day strength for almost all mixtures with a given clay. Three of the mixtures containing the coarse-ground clay in the 20:80 ratio to cement showed higher strength at 28 days than did the 1:3 cement mortar. These contained shales 6 and 8 and underclay 14.

More finely-ground clay (passing an 80-mesh sieve) gave mortars of lower strength than did the 8-mesh material in all cases except three. In some instances, the decrease was considerable, either at seven or 28 days or both. Only the mortars containing shales (20 and 17) or glacial till (3) developed somewhat higher strength with the finer clay material. With the exception of the 20:80 mixture of shale (17), all of the mortars containing the finely-ground clay showed lower strength in both the seven-day and 28-day tests than that of a 1:3 cement-sand mortar. So far as mortar strength is concerned, the fine grinding of the clay portion gives little, if any, advantage. It is evident that there is sufficient slaking of most of the clays, even the harder shales, in the mixing of the mortars to obviate the need of finer grinding. These results indicate that a portion of the clay, at least, functions as an aggregate in the same manner as the sand. Probably the gradation in particle sizing of the clay portion will have a significant effect in relation to the density developed by the packing of the particles in the mortar mixture. The amount of slaking and break-down of the clay in wetting and mixing is a factor in this connection.

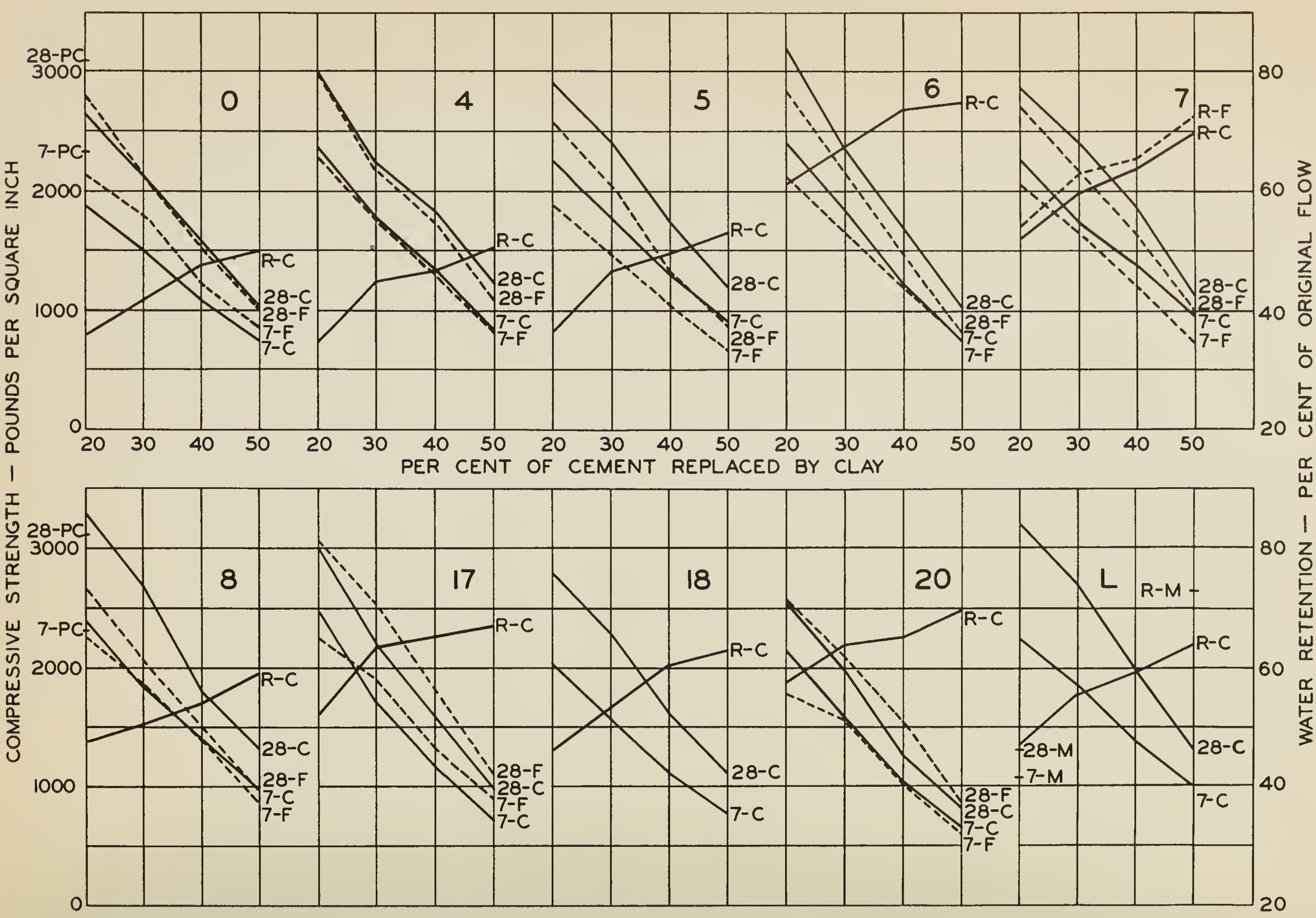

Fig. 3. - Compressive strength and water retention of mortars with admixtures of shale.

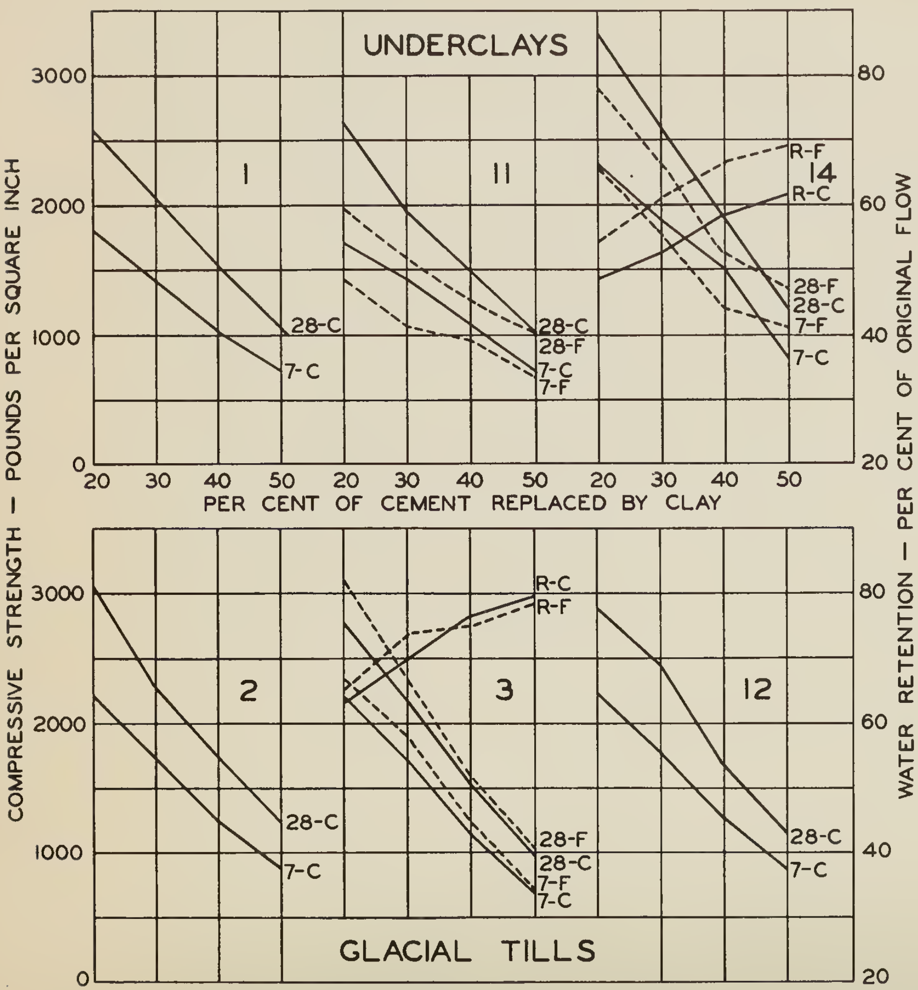

Fig. 4. - Compressive strength and water retention of mortars with admixtures of underclays and glacial tills.

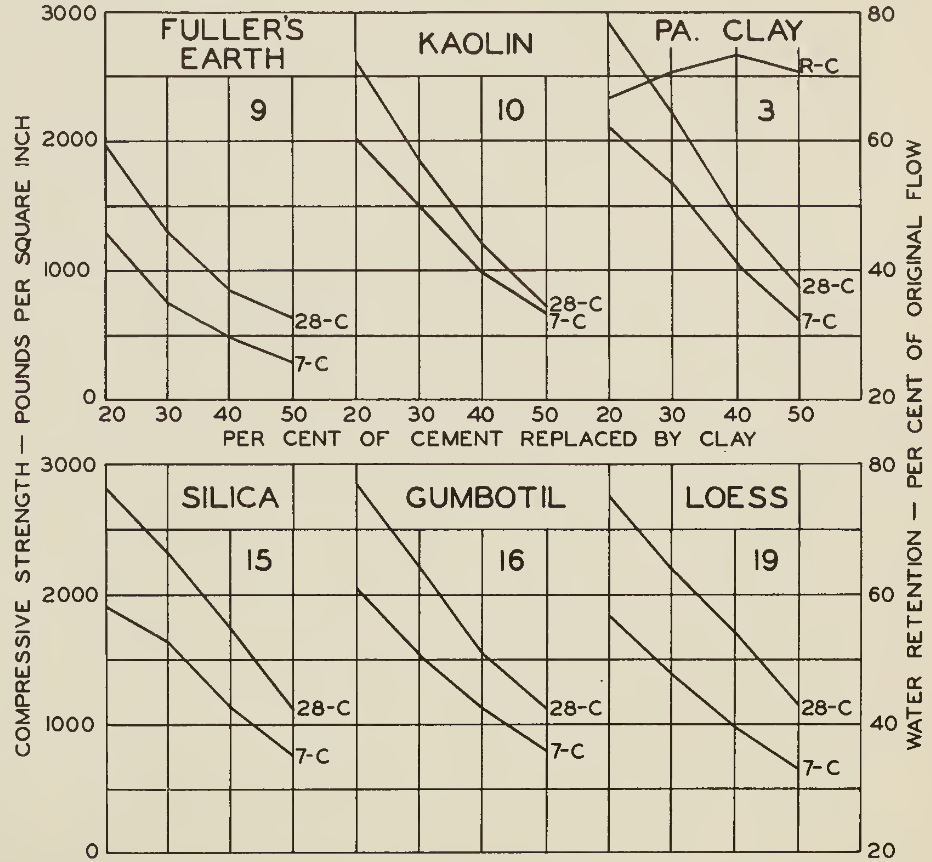

Fig. 5. - Compressive strength and water retention of mortars with admixtures of miscellaneous clay materials. (Note: Sample 3 is Pennsylvanian or "Coal Measures" clay.)

It is possible that other properties of the mortar, such as weather resistance, may be affected to a greater extent by the use of finer clay material and to such a degree that it may be desirable. This must be determined in further investigation.

The maximum amount of clay that may be safely incorporated in a mortar mixture will be determined, to a considerable degree, by the strength that will be developed in setting. Definite strength requirements are not included in some of the specifications for masonry mortars.

Federal Specification SS-C-181b for masonry cement requires a minimum strength of 250 lbs. per sq. in. at seven days and 500 lbs. per sq. in. at 28 days for Type I, which is intended for use where not exposed to frost action. For general masonry use, Type II materials should have a minimum compressive strength of 500 lbs. at seven days and 1000 lbs. at 28 days.

In Brick Engineering,1/ it is suggested, in connection with weather resistance, that the minimum strength at seven days should be 600 lbs. per sq. in. In specifications for lime-cement-mortars, three classes and their requirements are designated.

The 1:1:6 mortar(cement, lime-putty, and sand by volume) (minimum compressive strength at seven days = 400 lbs. per sq. in.) is suitable for general use above grade and is recommended specifically for parapet walls, chimneys, and exterior walls subject to severe exposure, also for structural clay tile construction.

The 1:2:7-9 (cement, lime-putty, sand) mortars, having a minimum seven-day strength of 150 lbs. per sq. in., are suitable for non-load-bearing walls not subjected to severe exposures, also for load-bearing walls in which unit compressive stress is not excessive. The $1:\frac{1}{4}:2\frac{1}{2}$-3 mortar (cement, lime-putty, sand) with a minimum strength of 1500 lbs. per sq. in. at seven days, is suitable for general use and is recommended specifically for reinforced brick masonry and for plain masonry below grade or in contact with earth, such as in foundations, retaining walls, walks, sewers, manholes, and catch basins.

For every clay tested, mortar strength was sufficient, even with equal parts of clay and cement, to exceed the requirement for Type I in the Federal Specification. The strength requirements for Type II mortars, suitable for general use, are fulfilled by mortars in which clay material replaces 40 per cent of the cement for all the shales, underclays, glacial tills, and other materials except fuller's earth. In the 50:50 mixtures, shale (20) was slightly below the 28-day requirement and materials 9, 10, and 13 were also somewhat deficient in 28-day strength.

The strength of mortars in which 40 per cent or more of these clay materials replaced cement was equal to or greater than that of the commercial masonry cement for nearly every sample. It is evident that relatively large quantities of these shales and clays can be incorporated in mortars for ordinary masonry purposes and that they will be

1/Brick Engineering, H. C. Plummer and L. J. Reardon - Structural Clay Products Institute, p. 51, 1939.

... as high in strength as are prepared mortars now on the market and in general use.

If a minimum compressive strength of 1500 lbs. per sq. in. at seven days is satisfactory for mortars subject to the most severe requirements of ordinary masonry, the present tests show that considerable amounts of the majority of the clays tested may be used. In most cases, the compressive strength does not fall below this value until the ratio of clay to cement reaches 30:70 to 35:70 by weight. These mortars would contain the following proportions by weight of the three ingredients: 1 cement - 0.43 clay - 4.29 sand; and 1 cement - 0.54 clay - 4.62 sand, respectively.

Water Requirement for Standard Consistency.--The water requirement for the specified consistency for compressive strength specimens is somewhat lower than would probably be used in mortars for masonry purposes. These stiffer mortars, with a flow of 65-80 per cent, are more suitable for molding the two-inch cubes than would be a mortar of 100-115 per cent flow, specified for water retention tests. The latter is about the consistency used by the brick mason. The water requirement for 100-115 per cent flow is found to be about 1 to 3 per cent higher than that for 65-80 per cent flow in some of the mortars containing various proportions of clay materials.

A considerably larger amount of water is needed in the clay-cement mortars than when cement alone is used with the sand. The requirement increases with larger proportions of clay, as shown in figure 6. In general, the clays which require the larger amounts of water to produce the desired mortar consistency give lower-strength mixtures than do the clays requiring less water. This is particularly noticeable with fuller's earth (9), and to a less degree with the kaolin (10) and the "Coal Measures" clay (13). The effect in the latter two is best seen in the diminishing gain in strength from seven to 28 days as the proportion of clay is increased. In the shales, the differences in water requirement of up to 40 per cent mixtures is not great and little effect on mortar strengths is evident or should be expected.

It would be expected that a high water addition in the mortar would cause lower strength, due to a greater degree of porosity. The effect might be offset by shrinkage in setting and drying, but this would be objectionable in a masonry mortar. On the other hand, higher water content should tend to give a greater yield or volume of mortar per unit weight of solid material. The relative yield of the different mixtures has not been determined.

Water Retention.--The results of water retention tests for a number of the samples are shown with the strength data in figures 3, 4, and 5. The values for mortars containing the various proportions of the 8-mesh clay material are shown by curves marked R-C. Results with 80-mesh clay material are shown for three samples by dotted curves R-F. The value for the masonry mortar is shown in Figure 1 with the lime-cement mortar data (L) by the point R-M.

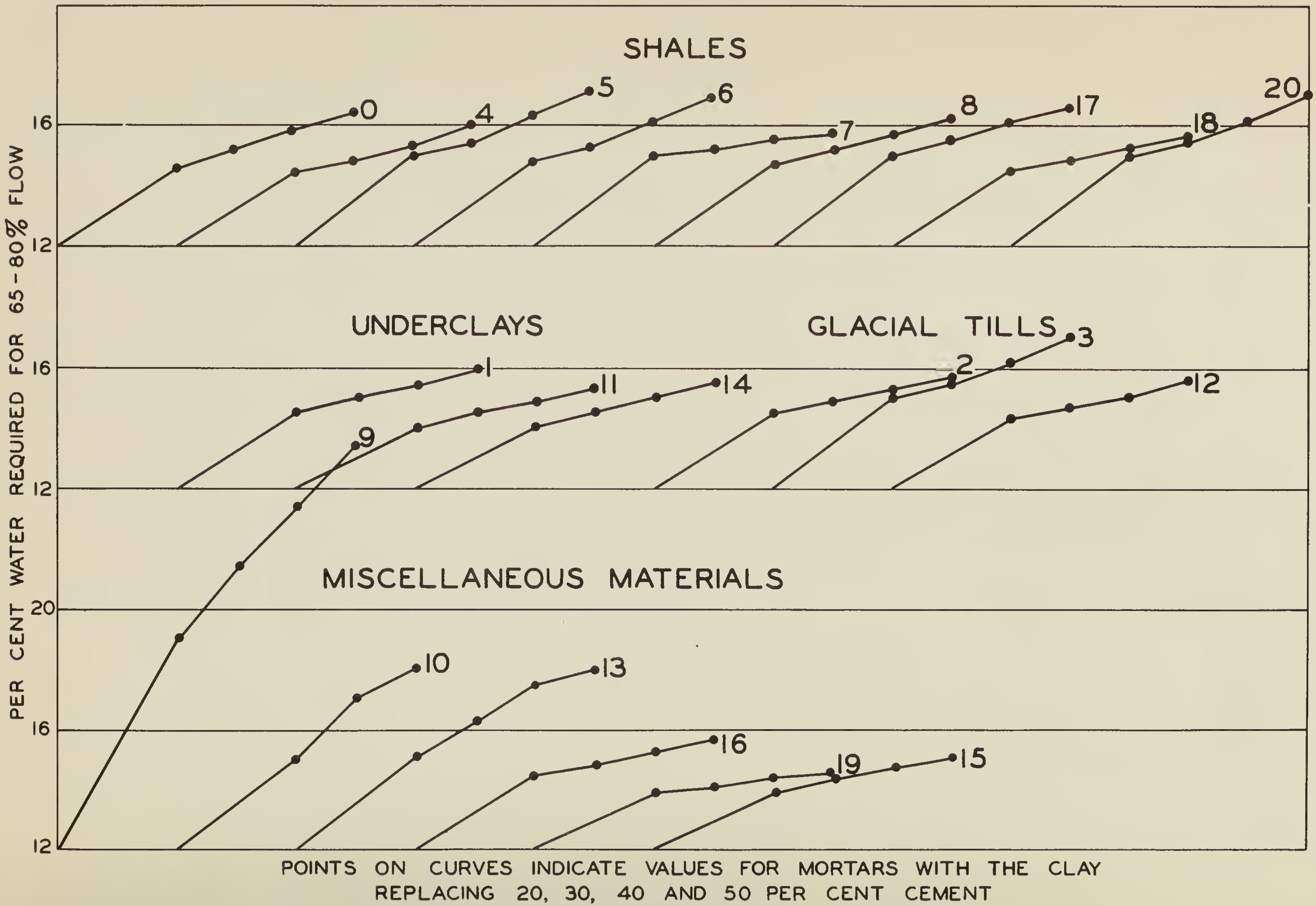

Fig. 6. - Water required for standard consistency in compression test specimens.

Some of the samples show high values of water retention, considerably above that of the lime-cement mortars. These compare well with the prepared masonry mortar which showed a value of 73.3 per cent. The other samples show values equal to or only slightly lower than does the hydrated lime.

It has been noted that a water retention value of 65 per cent is considered desirable. Large proportions of some of the clay materials will be required to give this value while others can be used in lesser amounts. This indicates that increase in water retentivity will be obtained at the sacrifice of mortar strength and vice versa. Further tests on water retention, now in progress, will give desirable information on this relationship and, possibly, on some influences of the specific properties or characteristics of the clay materials themselves. None of the lime-cement mortars, made with the one sample of hydrate which was used, gave a water retention value of 65 per cent.

Discussion of Results

It is evident from the data on compressive strength of the mortars that a considerable proportion of the Illinois clays and shales are suitable for use as plasticizers in masonry mortar. It is indicated that they are equal to or superior to hydrated lime, when used in the same proportions, in producing mortars of satisfactory strength and that many are superior to the lime-cement mortars from the standpoint of water retention. In the testing procedure, it was observed that the workability of the clay mortars was generally much better than that of the lime mortars.

Clays which require large amounts of water to give a suitable working consistency are likely to produce mortars of inferior strength. However, most of the clays and shales which are most likely to be considered for use as mortar mix are satisfactory in this respect.

A considerable amount of most of the shales and clays may be incorporated in mortar without reducing the strength below the minimum requirements of specifications in common use. In general, these clay materials may replace 30 to 35 per cent by weight of the cement in 1:3 mortars intended for severe conditions of exposure. Mortars containing equal parts of clay and cement show sufficient strength to meet specifications for other types and uses.

There are evidences of some relationship between the characteristics of the clay materials and the properties of the mortars in which they are incorporated. These are not sufficiently well defined to discuss at this time. It is hoped that some correlations may be possible when the remainder of the experimental data has been obtained.